

The Harvest Experiment: Updates from the Platform and Regional Campaigns

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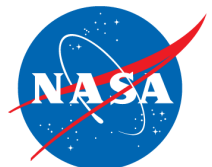
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September 27, 2018

Ocean Surface Topography Science Team Meeting

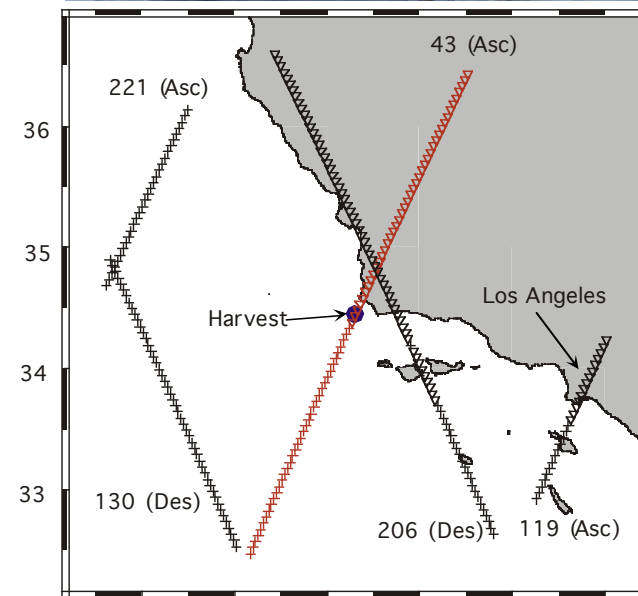
Ponta Delgada, Azores, Portugal





Harvest Platform

- **NASA Prime Verification Site for High-Accuracy Jason-class Altimetry (est. 1992)**
 - Open-ocean location along 10-d repeat track
 - 10-km off coast of central California
- **Provides independent measure of local geocentric sea level**
 - Precise GPS receivers
 - Redundant tide gauges (Bubbler, radar, lidar)
 - Local survey
- **Yields absolute SSH bias**
 - Also provides for monitoring of ancillary parameters (e.g., wet troposphere delay)
- **Supports collection of rich in-situ data set representing over 26 yr of continuous monitoring**
 - 365 T/P overflights spanning 10 years (1992–2002)
 - 259 Jason-1 overflights spanning 7 years (2002–2009)
 - 303 Jason-2 overflights spanning 8 years (2008–2016)
 - 96 Jason-3 overflights and counting (2016–)
- **Platform production remains on hold**
 - Future of platform not assured
 - Risk reduction activities underway



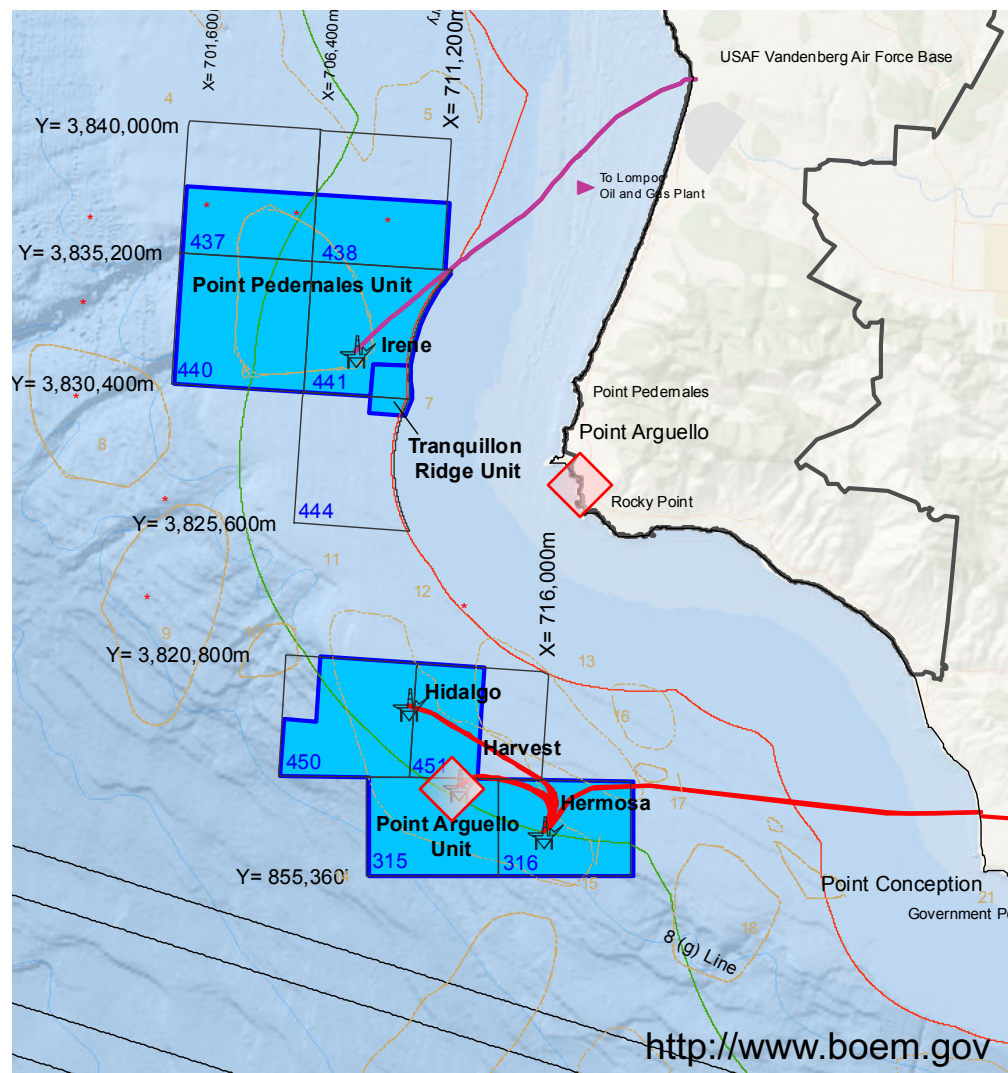


Highlights

- **Major Update to Model of Vertical Seafloor Motion**
- **New Tide-Gauge Technologies: Improving Prospects**
- **Updated Calibration Results for Sea-Surface Height and Path Delay Results: 26 Years**
- **Future of Harvest; Expanding the Calibration Footprint**
 - GPS buoy campaign underway
 - New land-based tide gauges

Vertical Land Motion from GPS

- Harvest (est. 1985) is the central of three oil platforms located over the Point Arguello offshore reservoir.
- Production began in 1991, peaked in 1994, and halted in 2015.
- Continuous GPS since 1992: one of the oldest GPS/tide gauge co-locations in the world.
- GPS at nearby Vandenberg AFB (est. 1992) provides onshore fiducial point away from reservoir subsidence bowl.
- Non-linear seafloor motions present significant challenge for altimeter calibration.

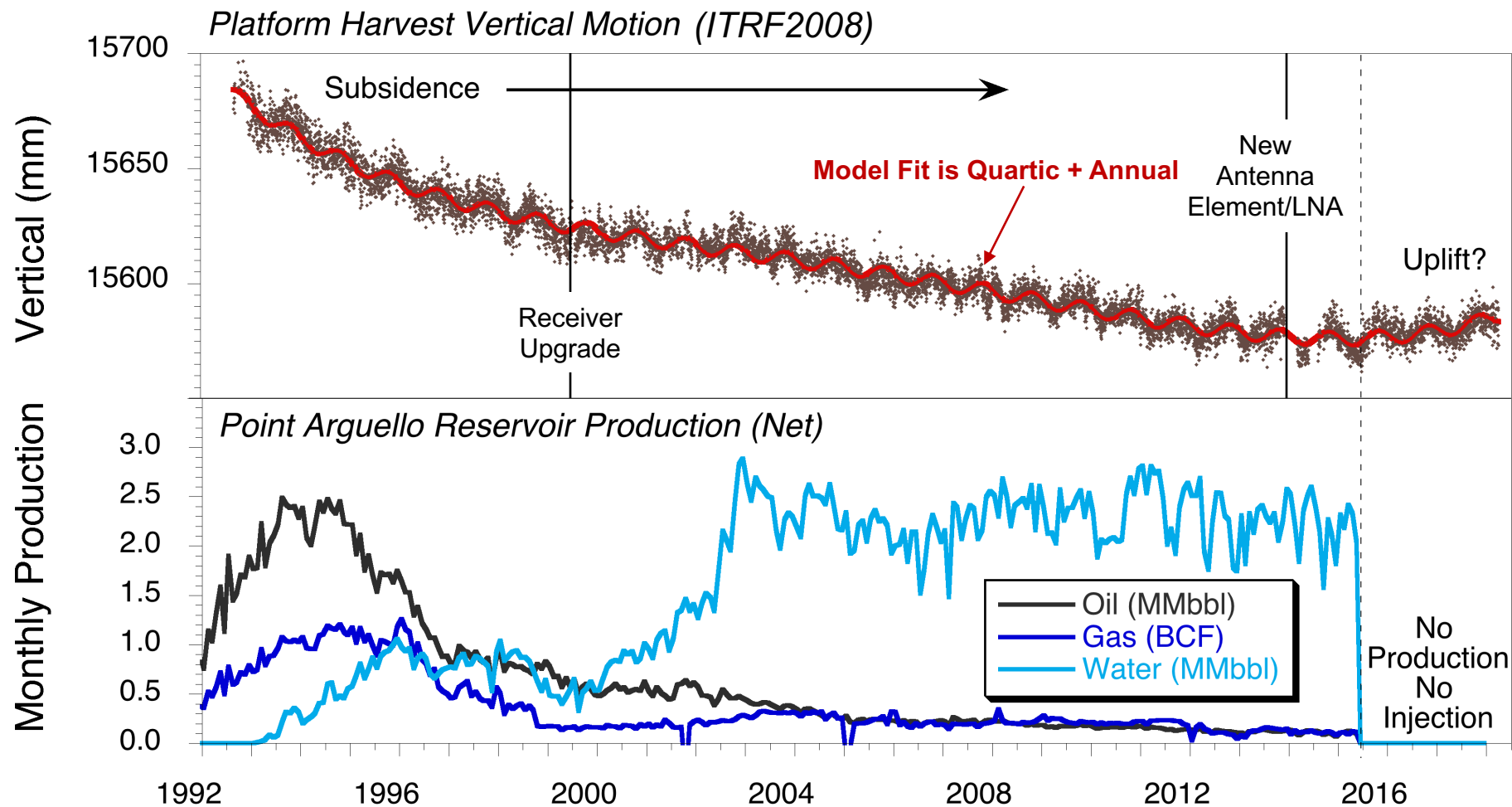


GPS Receivers

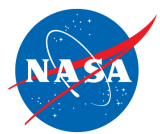


New Estimate of Vertical Seafloor Motion from GPS

Complex Pattern of Subsidence and Rebound

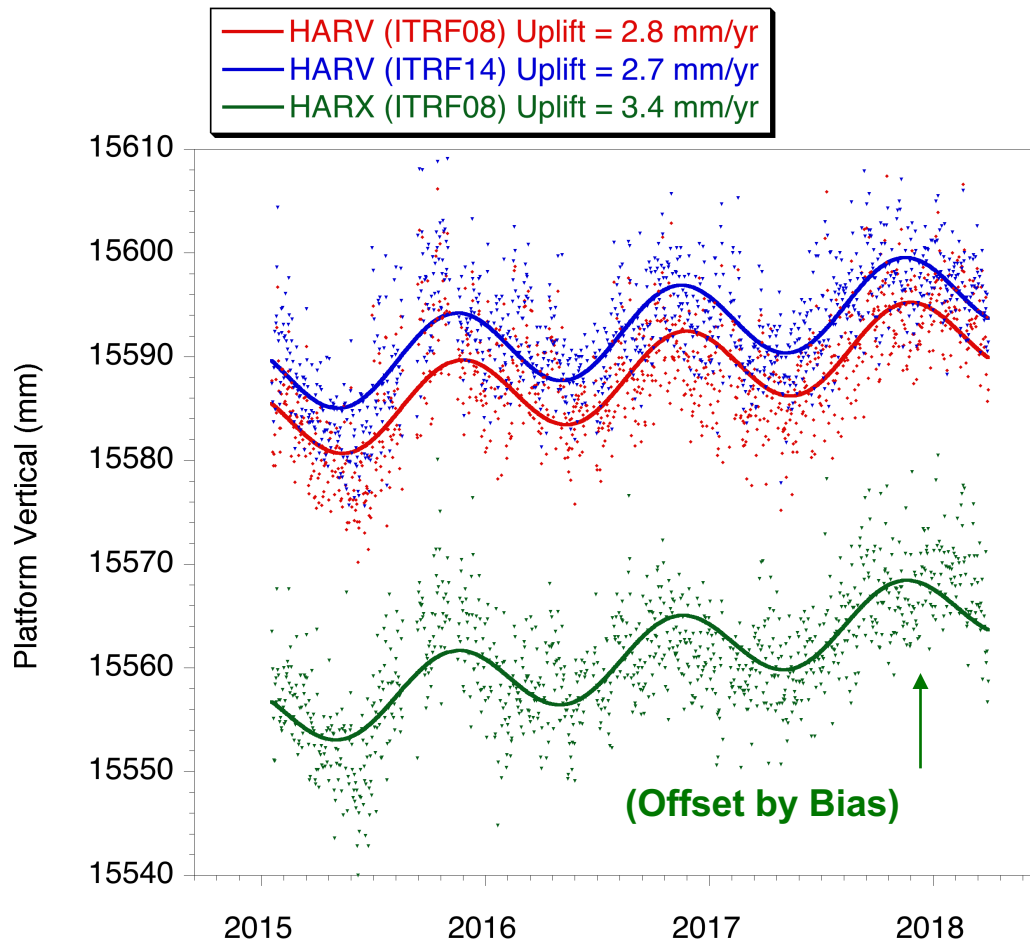


<https://www.data.boem.gov/Main/PacificProduction.aspx>



Current Estimate of Vertical Seafloor Motion from GPS Is Recent Uplift Real?

Application of New JPL GPS Orbit/Clock Products (in ITRF2014) and Use of Data from Independent Station* Show Similar Uplift (~3 mm/yr) since 2015

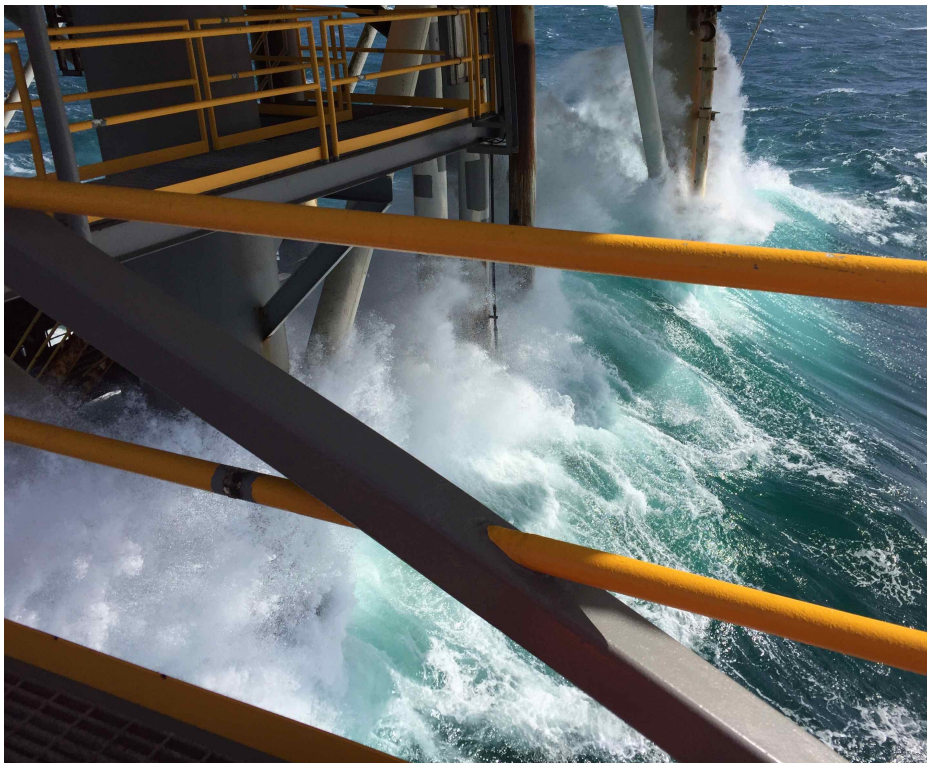


*Independent GPS system (receiver + antenna) installed in 2015 for monitoring purposes.

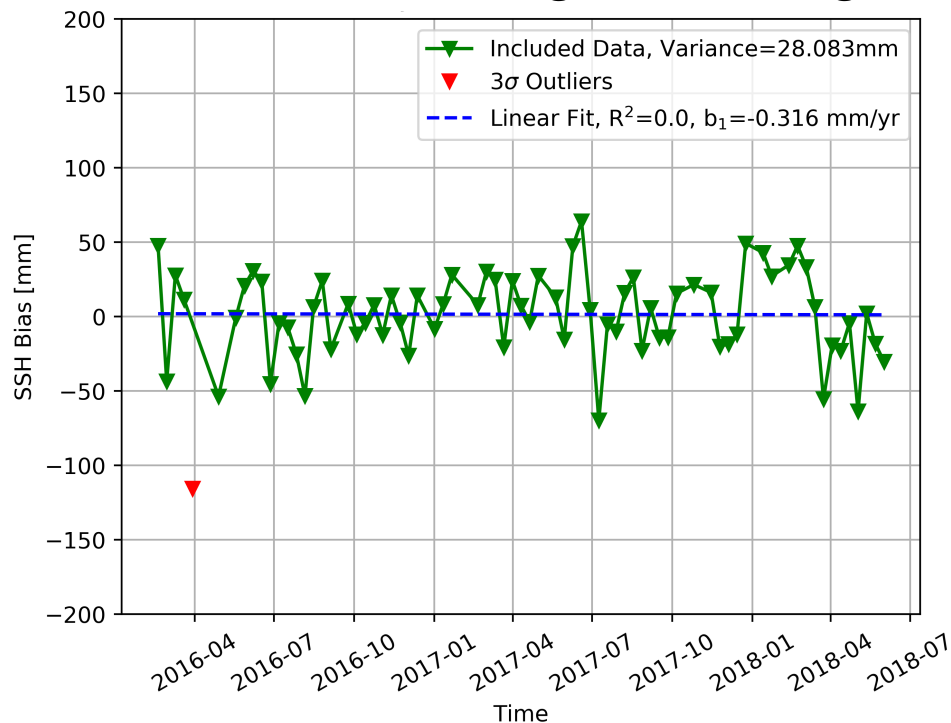


Platform Water Level from Tide Gauges

Update on Tide Gauge Performance in Heavy Seas



Jason-3 SSH Bias Using Radar Gauge



- Pressure (Bubbler) gauge has served as the standard at Harvest for many years, but has significant sea-state dependence and presents maintenance challenges.
- Radar gauges stable, accurate, and easy to maintain: gradually replacing submerged systems in NOAA network.
- Studies are ongoing to characterize remaining systematic errors from, e.g. wind waves, swell, sea spray and spume.
- Plan is to maintain pressure (Bubbler), radar and lidar systems operating simultaneously as long as practical.

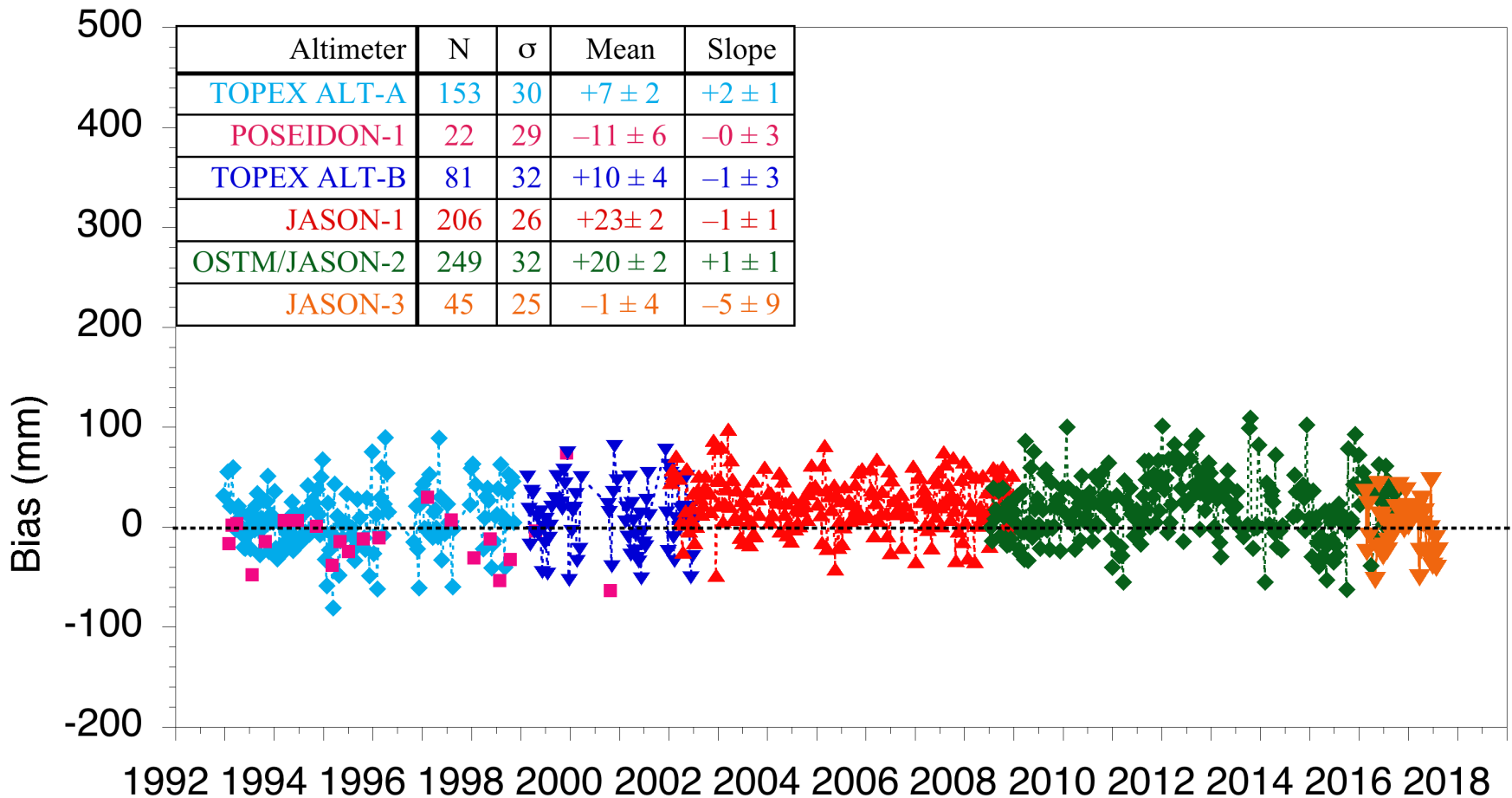


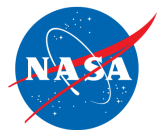
Harvest Long-Term SSH Calibration Record

Circa October 2017 (Miami OSTST)

Nominal Time Series:

T/P: MGDR + reprocessed orbits (*Lemoine et al.*, 2010) and wet trop. (*Brown et al.*, 2009); **Jason-1**: GDR-E; **Jason-2**: GDR-D; **Jason-3**: GDR-E



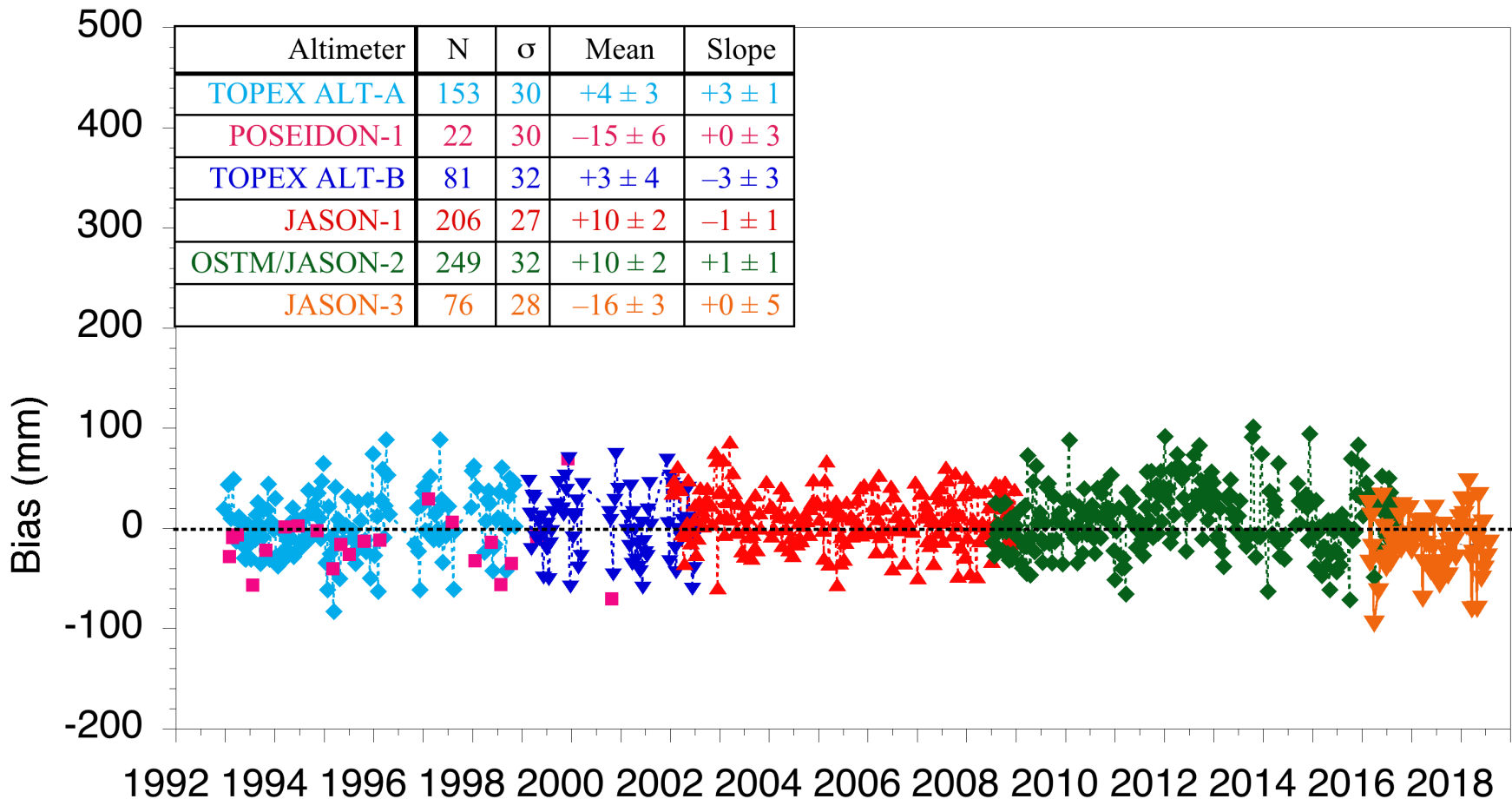


Harvest Long-Term SSH Calibration Record

Current Best Estimate (Using New Estimate of Seafloor Motion)

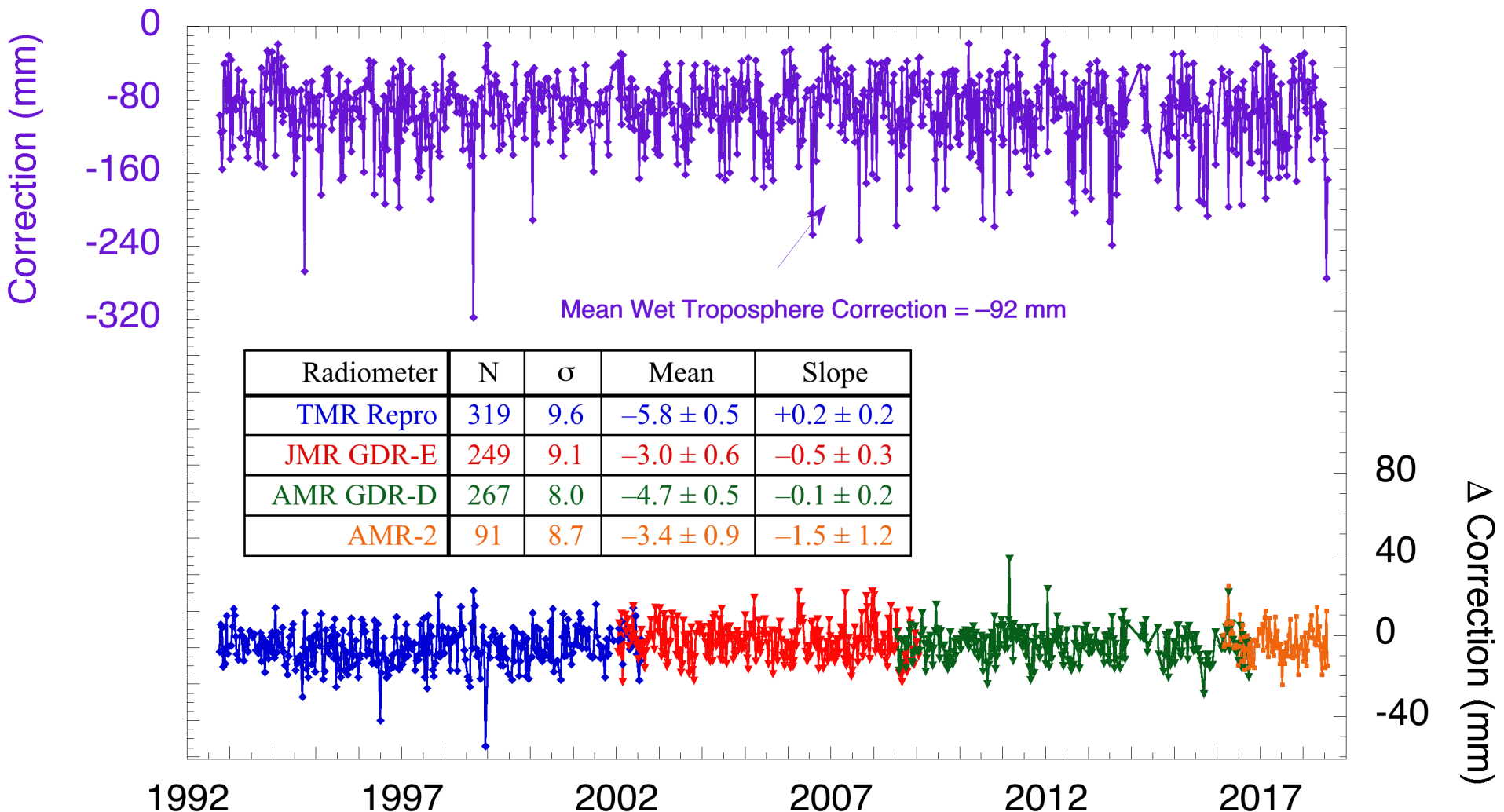
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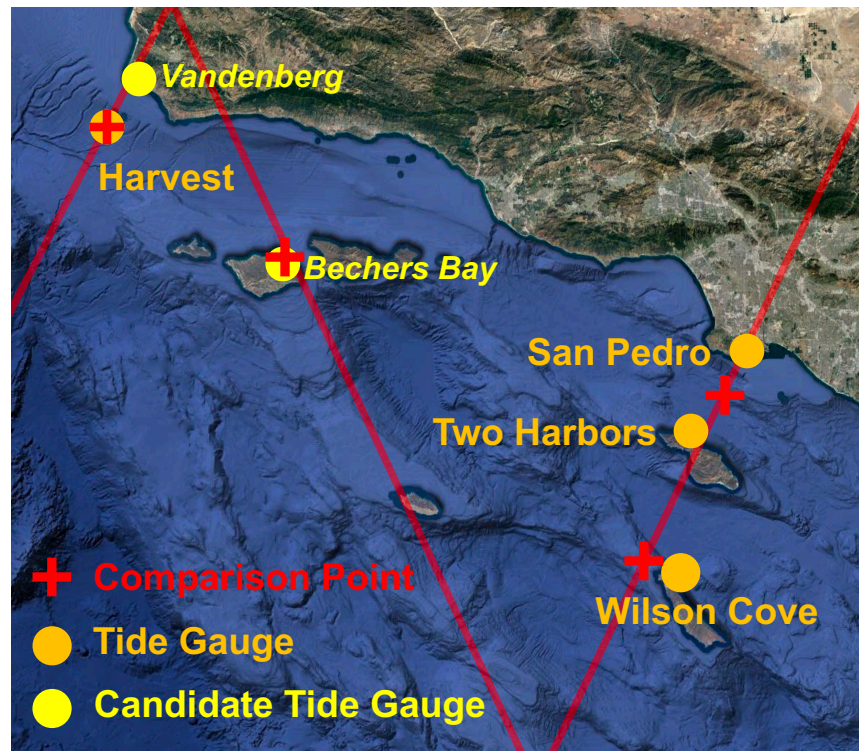
Wet Troposphere: Radiometer vs. GPS





Towards a Permanent Regional Network: *Provisional Tide Gauge Sites*

- **Lidar tide gauge (TG) installed 6/2016 on Catalina Island**
 - USC Wrigley Inst. for Environmental Studies near Two Harbors.
 - ~20 km (along Jason pass 119) to center of San Pedro Channel.
- **First altimeter vs. TG comparisons show promise**
 - 30-mm repeatability (N = 14 overflights) for comparison point in San Pedro channel.
 - But 45% of overflight opportunities eliminated on account of high backscatter (low winds).
- **Radar gauge installed 3/2017 on San Clemente Island**
 - NOAA/NOS COOPS sensor in Wilson Cove for 90 days
 - Comparison point is along unobstructed open-ocean approach.
 - Wind/wave conditions are intermediate: more active than San Pedro Channel, but less active than Harvest.
 - 24-mm repeatability (N = 9 overflights)
- **Two Additional Sites Under Consideration**
 - Vandenberg boat dock, close to primary (Harvest) Track, and permanent GPS at VAFB (est. 1992).
 - Bechers Bay on Santa Rosa Island (adjacent descending pass).



*Bechers Bay,
Santa Rosa Island*



GPS Buoy Project

- Joint NASA JPL, NOAA PMEL and U. Washington project funded through NASA ROSES call (Physical Oceanography)*

OBJECTIVES:

- Design, build and test a modular, low-power, robust, high-accuracy GNSS measurement system for long-term, continuous and autonomous operations on ocean- and cryosphere-observing platforms.
- Probe the limits of new kinematic precise-point positioning (PPP) techniques for accurately determining sea-surface height, and recovering neutral and charged atmosphere characteristics.
- Explore potential scientific benefits—in the fields of physical oceanography, weather and space weather—of accurate GNSS observations from a global ocean network of floating platforms.

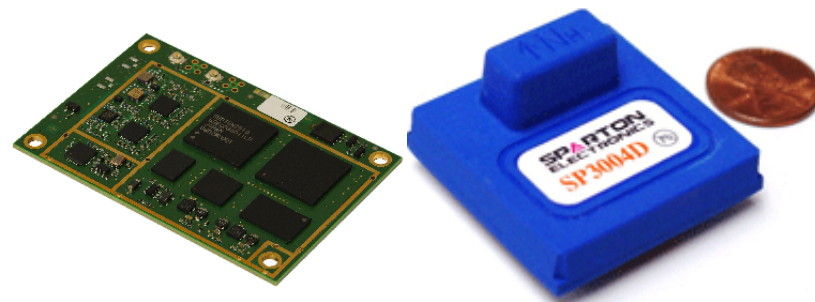
**Extending the Reach of the Global GNSS Network to the World's Oceans: A Prototype Buoy for Monitoring Sea Surface Height, Troposphere and Space Weather, B. Haines, S. Brown, S. Desai, A. Komjathy, R. Kwok, D. Stowers, C. Meinig and J. Morison.*



Prototype Precision GPS Buoy

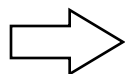
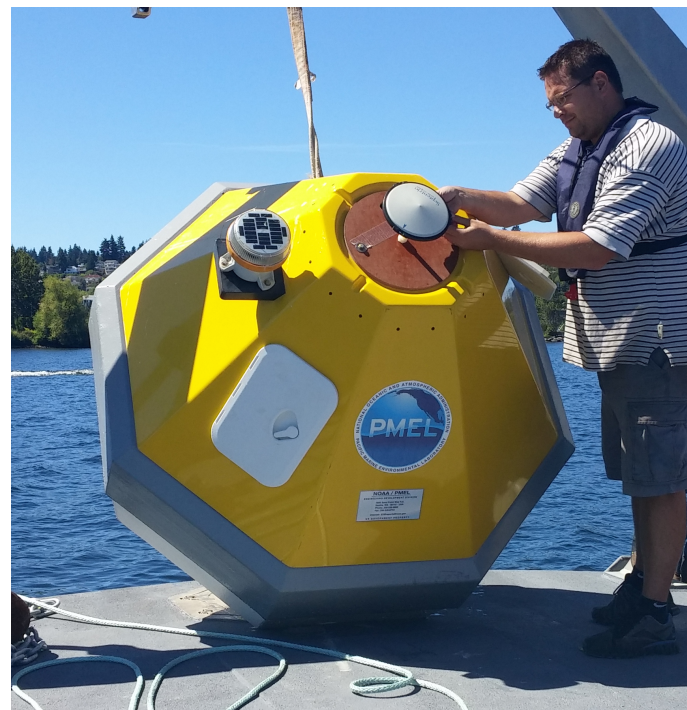
FEATURES

- Integrated low-power (~ 1 W), dual-frequency GPS system (Septentrio)
- Miniaturized digital compass/accelerometer.
- Iridium communications (presently used for basic heartbeat information).
- Adaptable to multiple floating platforms (e.g., buoys, wave gliders).
- Enables geodetic quality solutions without nearby reference stations.



DEVELOPMENT AND TESTING

- Buoy tested successfully under progressively more challenging conditions:
 - ✓ *Lake Washington (Aug. 7–12, 2015).*
 - ✓ *Puget Sound (Nov. 10 to Dec. 14, 2015).*
 - ✓ *Daisy Bank: open ocean Jason crossover location (May 11 to Sep. 8, 2016).*
 - ✓ *Monterey Bay: SWOT Pilot Experiment (June 22 to September 7, 2017).*

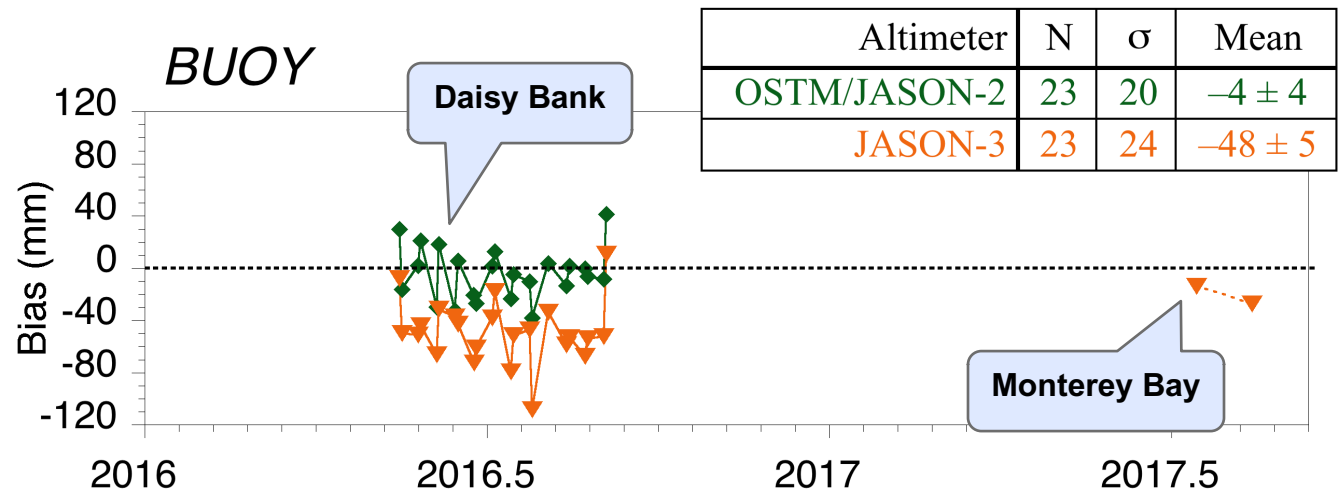
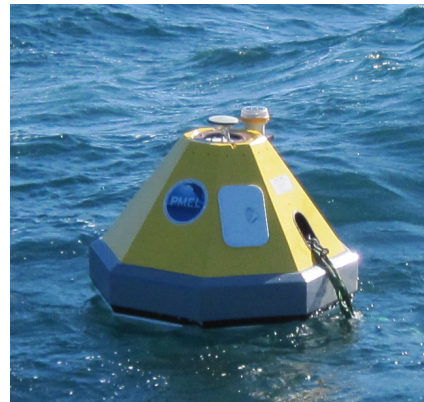
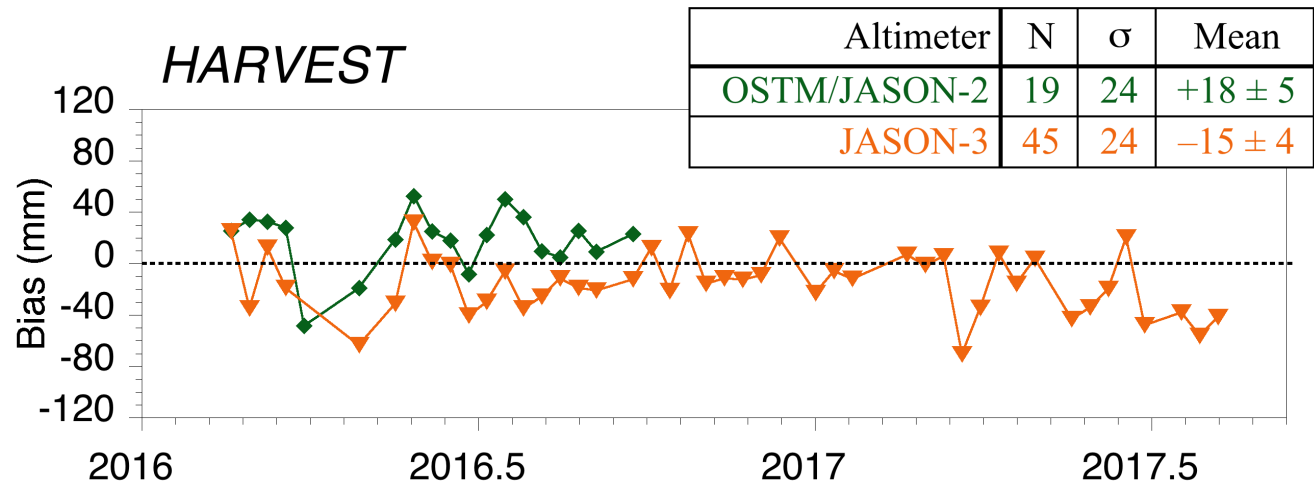


Total of 236 days in the water (20 days of data from Monterey Bay data lost due to failed USB drive).



Verification of Altimeter Sea Surface Height: Harvest vs. Buoy (Daisy Bank + Monterey)

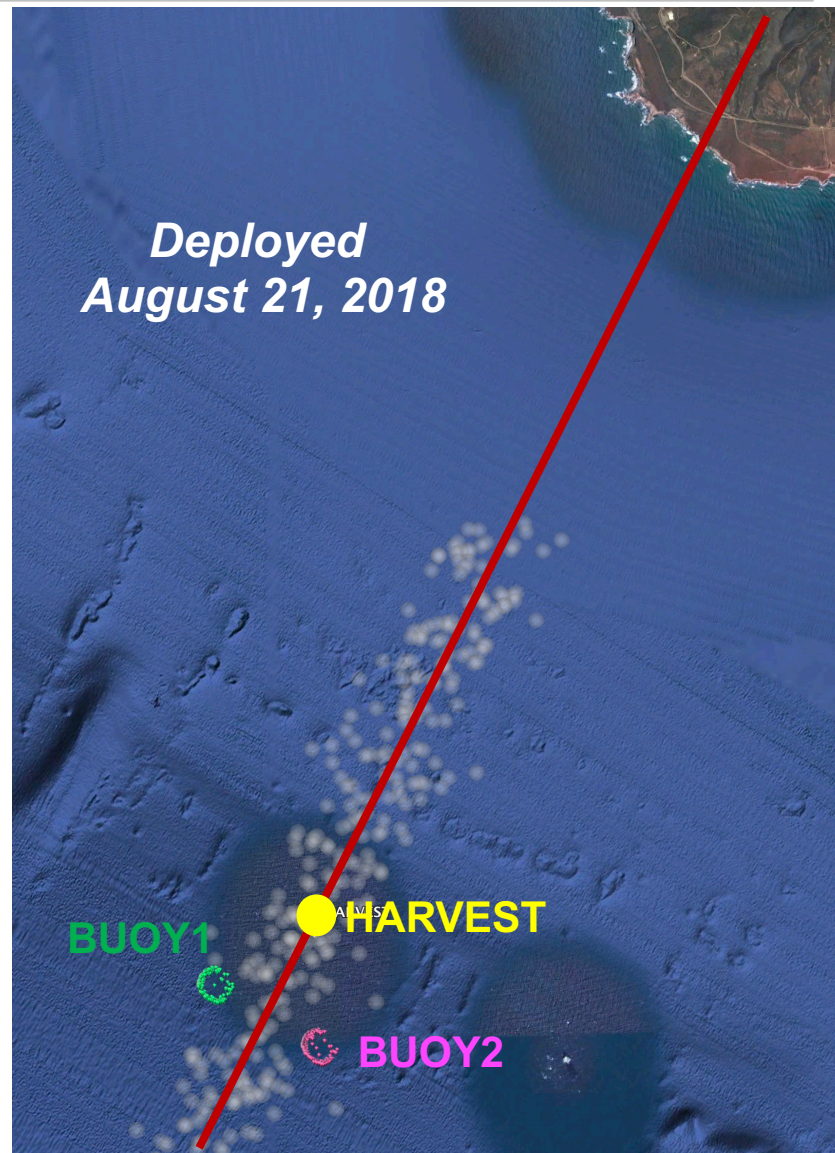
Comparable Results for the Jason-3 Era





Harvest Buoy Campaign: Aug. 2018 – Jan. 2019

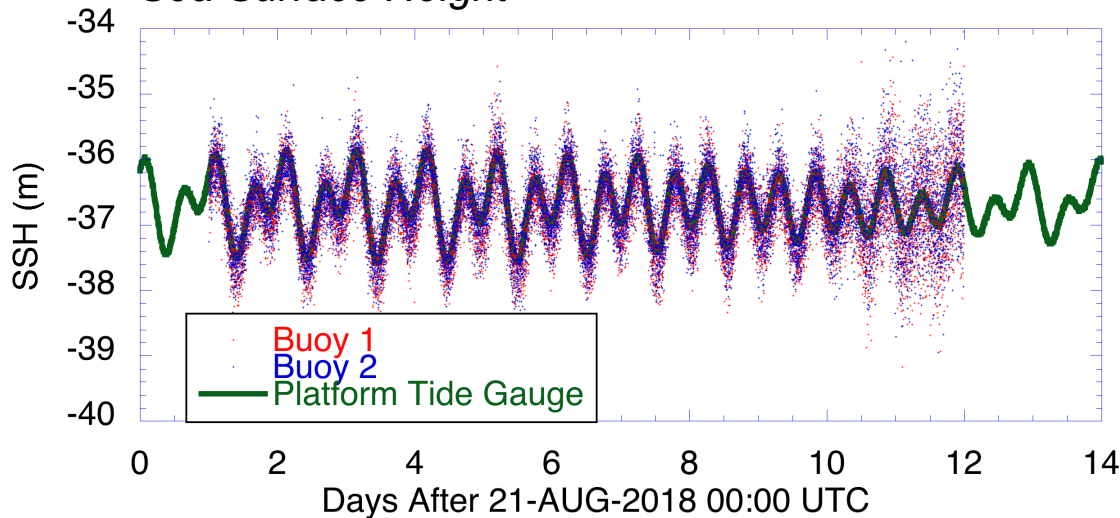
- Main goal: examine potential of precision GPS buoy systems to replace NASA Harvest verification site.
 - Risk reduction exercise for Jason-3 and Sentinel-6.
 - Anticipates possible platform loss or abandonment.
 - Buoys close to platform (~1.5 km) to support comparisons with platform tide gauges and overhead altimetry from Jason-3.
- Secondary goal: probe limits of GPS-based relative sea-surface height determination in open ocean.
 - Features two identically equipped surface buoys (new buoy modeled after prototype).
 - Buoys separated by ~1.5 km.
 - Short baseline will lend further insight on potential of GPS array for SWOT calval.
- Campaign enhancements
 - New longevity goal of 150 days: operate through higher (winter) sea states.
 - Buoys equipped with load cells to measure force on mooring (to study movement of buoy water line).
 - NOAA Prawler for taking Temperature/Salinity measurements along mooring.
 - Telemetry upgrade: 1-min snapshots of GPS tracking data to support basic positioning tests, and estimation of wet troposphere (1-Hz data saved onboard for recovery with buoys).



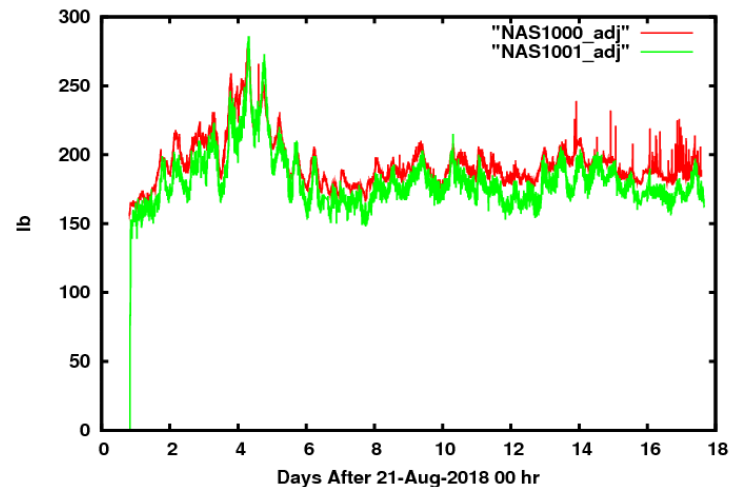


Early Results from the Harvest Buoy Campaign

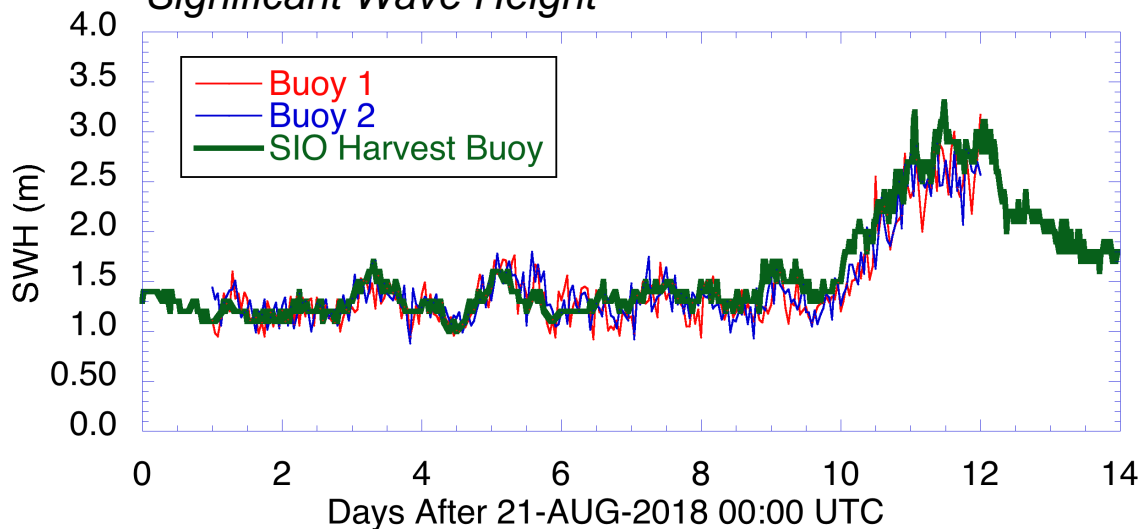
Sea Surface Height



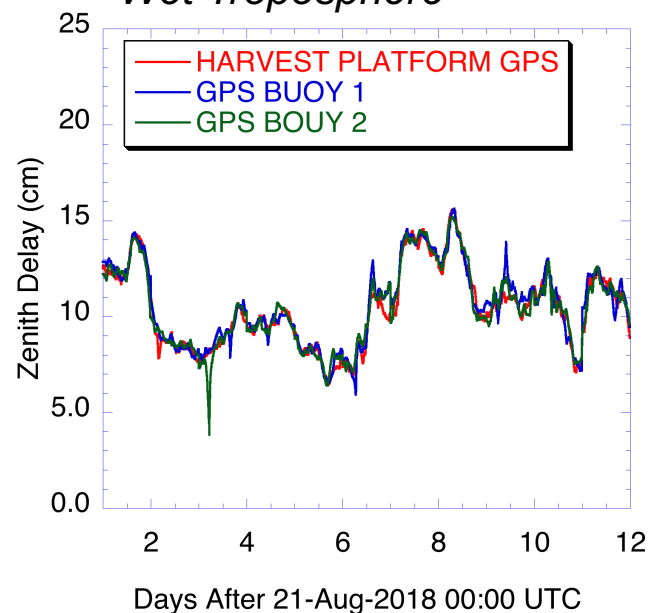
Load Cell



Significant Wave Height



Wet Troposphere





Summary

- **Absolute SSH bias from Harvest***
 - Jason-3: -16 ± 12 mm for GDR-E (thru Cycle 91 with N = 76)
 - Jason-2: $+10 \pm 10$ mm for GDR-D (N = 249)
 - Jason-1: $+10 \pm 10$ mm for GDR-E (N = 206)
 - ALT-B: $+3 \pm 10$ mm for MGDR+ (N = 81)
 - ALT-A: $+4 \pm 12$ mm for MGDR+ (N = 153)
 - POS-1: -15 ± 12 mm for MGDR+ (N = 22)
- **SSH drift at Harvest indistinguishable from zero for all systems**
 - ≤ 1 mm/yr for all systems except TOPEX (Side A).
- **Provisional tide gauges in Channel Islands**
 - Supplement Harvest for future missions (e.g., Sentinel-6, SWOT).
 - Provide some insurance against possible loss of platform.
- **Results from GPS buoy campaigns continue to show great promise**
 - Returned continuous, high accuracy data for Daisy Bank and Monterey Bay
 - Supported accurate retrievals of SSH, SWH, wet path delay and ionosphere.
 - Competitive with Harvest for all altimeter calibration metrics.
 - Harvest campaign underway with two buoys in platform vicinity.